Signal Theory

Toward a Unfied Theory of Psychedelic Action

or: “Hallucinogens and Recurrent Excitation in Cortical Circuitry”

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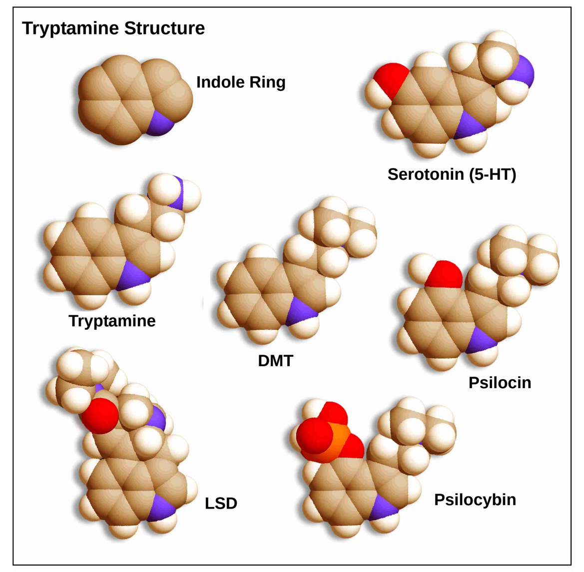
SUMMARY

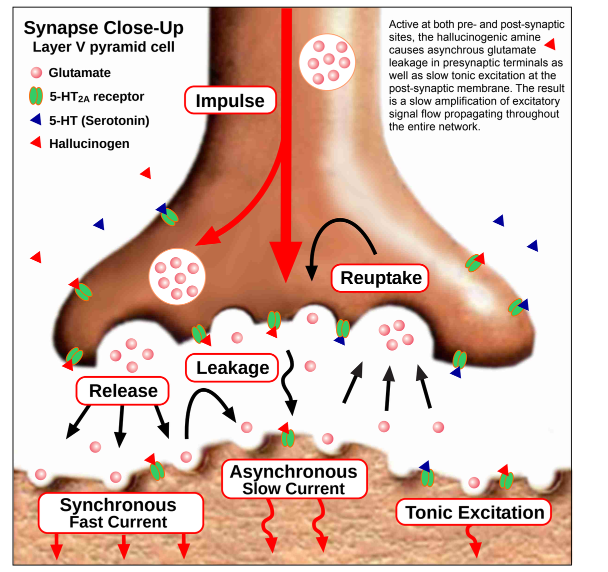
- Tryptamine hallucinogens are most active at the 5-HT_{2A} receptor subtype.
- The 5-HT_{2A} receptor subtype is densest in the recurrent cortical circuits of the sensory processing pathways.
- An increase in recurrent feedback excitation within the sensory processing cortices would lead to sensory signal gain, obsessive repetition of data, morphic distortion of data, and temporal lag in multi-modal sensory convergence.
- Thus, increased recurrent excitation within cortical circuits is the direct cause of perceptual distortions, hallucinatory constructs, and expanded states of consciousness associated with the psychedelic state.

THE ROLE OF 5-HT IN MODULATING RECURRENT EXCITATION



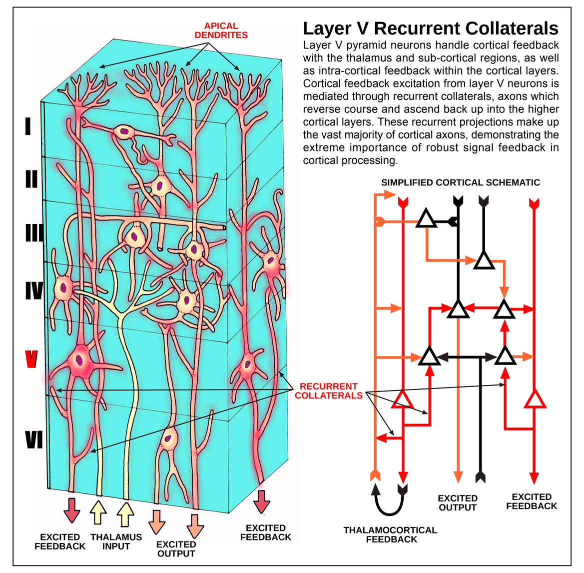
SEROTONIN AND TRYPTAMINE HALLUCINOGENS

The most potent visual hallucinogens are the tryptamines, such as DMT, psilocybin, and LSD, which closely resemble serotonin. The indole ring each tryptamine carries is like a tiny key for a specific receptor subtype known as 5-HT_{2A}. 5-HT (5-hydroxy-tryptamine) is the chemical name for serotonin, and the 5-HT receptor subtype targeted by hallucinogens is densest in the recipricol dendrite arbors of the sensory processing cortices.



5-HT AND ASYNCHRONOUS EXCITATION

5-HT_{2A} partial agonists have been shown to cause a slow asynchronous leakage of glutamate from pre-synaptic terminals in layer V pyramid cells. Glutamate is an excitatory transmitter, and this small asynchronous leakage amplifies the duration and intensity of incoming sensory stimulus. When this slight amplification is applied to recurrent circuits in a neural network, the excitatory effect is multiplied and rapidly spreads across the entire network.

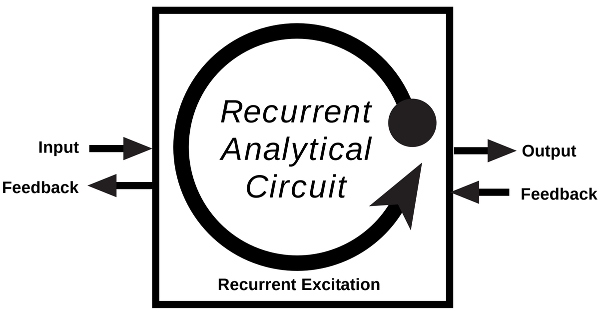


LAYER V NEURONS AND RECURRENT EXCITATION

Layer V pyramid neurons are not only dense with 5-HT_{2A} receptor sites, they are also critical in handling feedback excitation both within the cortex and between cortical and sub-cortical regions. When viewing cortical circuits from a schematic standpoint, it is easy to see how even mild excitation in layer V signal processing can quickly spread throughout the entire cortical circuit to increase recurrent excitation and amplify sensory signal output.

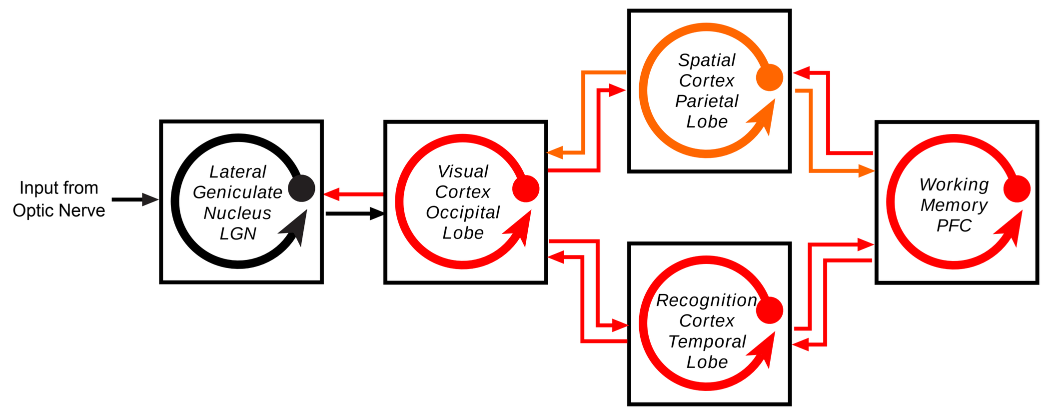
RECURRENT EXCITATION IN ANALYTICAL SENSORY PROCESSING

- Recurrent excitation is just another word for *feedback*, the process in which a portion of the output of a specific circuit is redirected back into its own input for further analysis. Feedback excitation in cortical circuits is used to amplify signal, improve signal fidelity, and refine detail resolution.
- Recurrent excitation may be thought of in terms of an optical scanner that must make multiple passes over the same image to acheive high levels of detail resolution. Each successive feedback pass refines detail resolution and enhances sigal fidelity.
- Feedback excitation in cortical circuits is responsible for signal analysis, data discrimination, detail resolution, manipulation of data in working memory, compression of data in long-term memory, fine motor control, as well as many other extremely important cognitive functions.
- An interruption of recurrent excitation could lead to disorientation, loss of cognitive focus, loss of memory recall, and loss of fine motor control.
- An increase in recurrent excitation could lead to amplification of sensory signal intensity, enhanced detail resolution, enhanced analytical processing, and states of expanded consciousness.
- Runaway (unchecked) feedback excitation could lead to perceptual distortions, obsessive ideation, hallucinations, loss of synchrony in multi-modal sensory cohesion, psychosis, catatonia, and (at the extreme end) epileptic seizure.



Recurrent cortical circuits are subject to both internal feedback (open loop excitation) as well as upstream feedback from downstream circuits (closed loop feedback).The total amount of circuit feedback depends upon the intensity of feed-forward and feedback input stimulating the circuit at any one time.

RECURRENT EXCITATION IN VISUAL PROCESSING PATHWAYS



The above circuit illustration shows the various layers of recurrent analysis along the visual processing pathway. The areas in orange and red indicate where recurrent excitation would be highest, based on the distribution density of 5-HT_{2A} receptors in the cortex. The cascade of recurrent signal feedback along the entire visual pathway can lead to extreme perceptual distortion and eventual loss of network stability. While this schematic is for the visual pathway, a similar schematic could be applied to audio, somatic, and memory pathways as well.

The sensory processing pathways in the cerebral cortex contain many analytical circuits that derive processing power from the recurrent parsing of sensory input. Each recurrent circuit has a specific analytical function, and ambiguous or emotionally salient data may be re-routed through the same circuit multiple times to boost signal fidelity and enhance data resolution. As incoming sense data resolves through each circuit, output is fed forward as a progressive scan with a delay, or lag, of a few milliseconds for each sucessive circuit iteration.

As recurrent circuits become excited, they act as signal attractors, or “traps”, for any incoming data that requires refined analysis. Data that is being actively scrutinized must be held in recurrent analysis until the integrative threshold of that specific data set has been reached. Once the circuit resolves the data, it drops the recurrent signal and moves onto the next piece of sensory input, all the while relying on instantaneous feedback from downstream circuits to confirm data reception and/or request further analysis on a specific set of data.

When these recurrent circuits become excited in the presence of a hallucinogen, all incoming sensory data is “trapped”, intensified, compulsively scrutinized, and obsessively analyzed. This can result in expanded states of awareness as well as pathological ideation and/or psychotic distortions of incoming data. The perceptions which arise from this state may be amazingly perceptive or cartoonishly absurd, depending on the dose of hallucinogen taken.

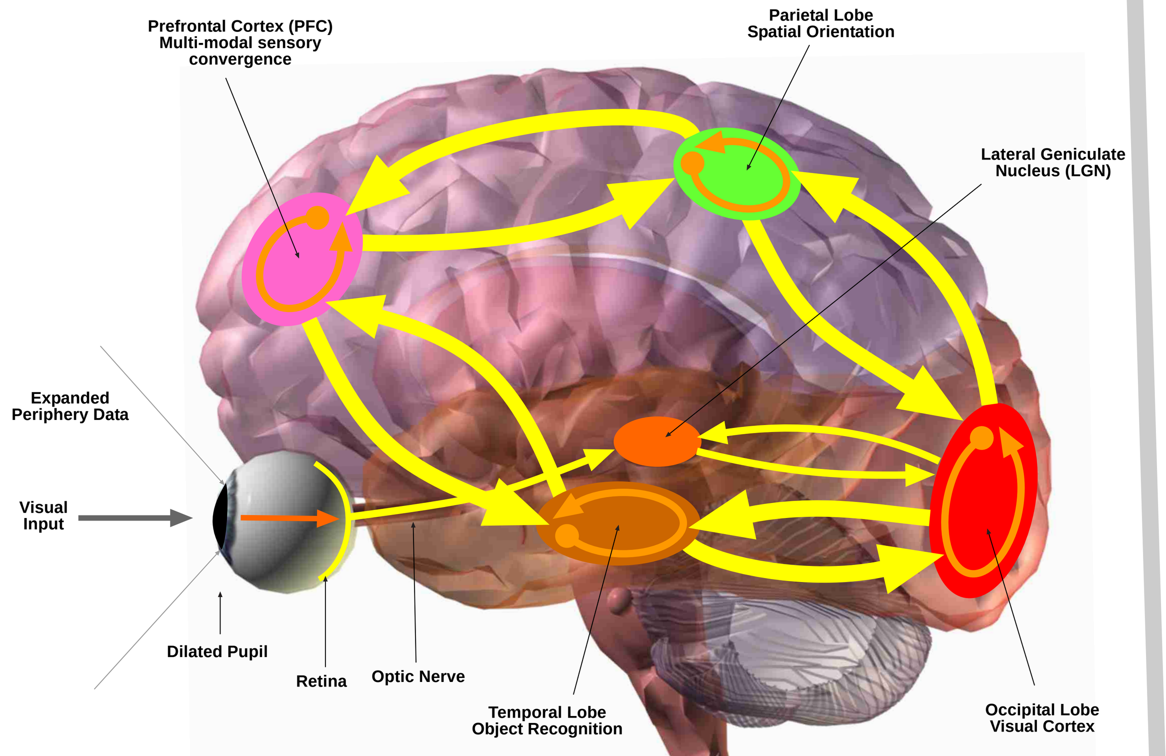
RECURRENT EXCITATION AND PARANORMAL PERCEPTION

The primary area where recurrent circuitry is used to amplify incoming visual signal is in the visual cortex. The layer V pyramid cells of the visual cortex contain more 5-HT_{2A} receptors than any other part of the brain, and all of these receptors are used to modulate recurrent excitation both within the visual cortex and between the visual cortex and the LGN. Excessive recurrent excitation in this feedback circuit is responsible for the intensification of colors and morphic distortion in line and texture resolution associated with psychedelic states.

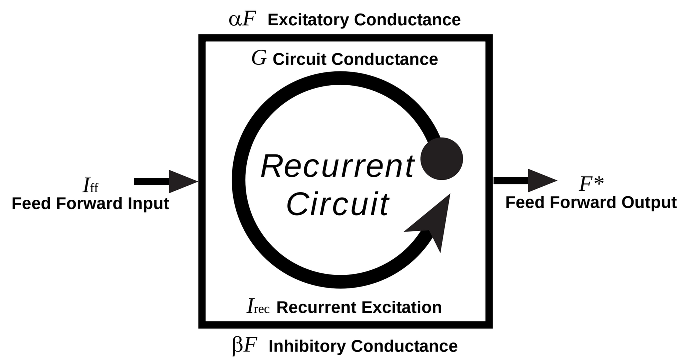
From the visual cortex, signal diverges and feeds-forward to the analytical processing centers of the temporal and parietal lobes. The temporal lobe circuitry is engaged to determine “what” is being viewed, while the parietal lobe circuitry determines “where” everything is in relation to everything else. Both of these circuits rely on recurrent excitation to preserve moment-to-moment contextual data as well as provide robust analysis of incoming data.

When analyzing the trajectory of a moving object, data must pass back and forth between the visual cortex and the spatial cortex multiple times in order to update the location of the moving object over time. Excessive excitation in this reciprical circuit causes the trajectory of the moving object to decay from visual memory at a much slower rate than usual, thus causing moving objects to leave “trails” in the field of vision under the influence of a hallucinogen. The time decay of these visual trails is directly proportional to the intensity of feedback within the circuit, which is dependent on the dose and receptor affinity of the hallucinogen.

While visual trails are easy enough to illustrate, another intriguing phenomenon arises when recurrent circuitry between the visual cortex and the object recognition cortex becomes excited. In this state, each object that is scrutinized immediately takes on deep significance. Everyday objects seem loaded with history and personal meaning; simple textures and odd shapes reveal hidden images and buried memories; the mundane suddenly becomes infinitely fascinating. This excercise of finding deep understanding in the simplest of objects is often referred to as “enlightenment” or an “expanded state of consciousness”.



MATHEMATICAL MODEL OF A SIMPLIFIED RECURRENT CIRCUIT



Recurrent Excitation: $I_{rec} = (\alpha - \beta)F$

F^* **Firing Frequency:** $I_{ff} + (\alpha - \beta)F^* = GF^*$

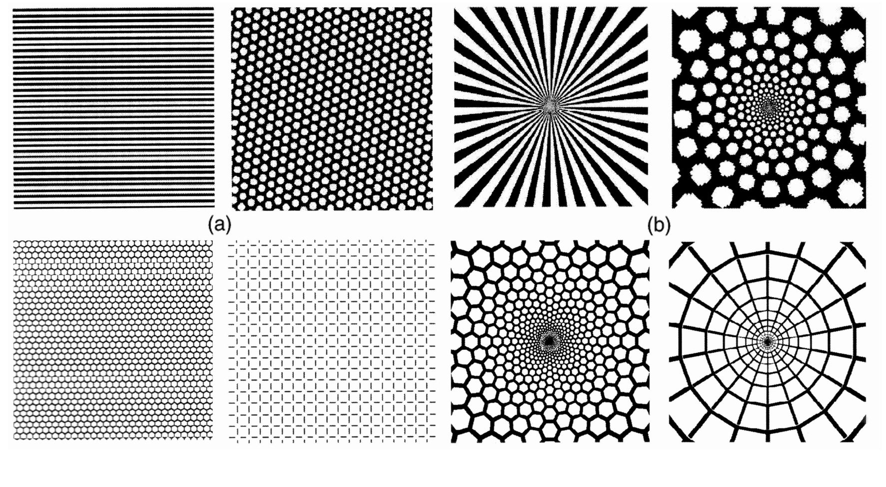
Total Circuit Gain: $1/(G + \beta - \alpha)$

The illustration to the left shows a simplified model of a recurrent circuit in the visual cortex. The variable I_{ff} represents the amount of feed-forward input being sent to the circuit, the variable G is the general conductance of the entire circuit, and the variable α represents the excitatory conductance of the circuit. In this model, the excitatory influence of a hallucinogen would be applied to the variable α, which enhances the total circuit conductance and, in the absence of proportional inhibition (variable β), amplifies signal gain across the circuit.

As the excitatory conductance of α rises, there is a chain reaction of responses within the recurrent circuit. First, the effective conductance of the circuit rises, causing the level of recurrent excitation (I_{rec}) applied to incoming signal (I_{ff}) to rise in direct proportion. The result is both an amplification of signal intensity as well as a slight delay, or lag, in feed-forward signal integration proportional to the gain on that individual circuit. Divergent lag in recurrent cortical circuits leads to loss of synchrony in multi-modal sensory convergence, causing spatio-temporal distortion of incoming sense data.

Due to the slow asynchronous release of glutamate in the presence of a 5-HT_{2A} partial agonist, the value of α would be expected to rise steadily over the duration of an entire psychedelic trip. As the gain on a specific circuit rises and approaches 1, neurons within that circuit will quickly reach maximal discharge in the presence of even the smallest stimulus. If the circuit gain exceeds 1, no external stimulus is needed to promote circuit activity; recurrent excitation alone is enough to keep the circuit actively feeding ‘phantom echoes’ of sense data forward.

SIGNAL EXCITATION, STABILITY, AND FRAME TRANSLATION ERRORS



The above panels show bifurcating patterns in spatially oriented cortical (a) and retinal (b) networks. The top panels show patterns arising from distance-dependent connections, the bottom show distance- and orientation-dependent connections (Bressloff, et. al).

Human perception relies on a complicated network of recurrent circuits acting in unison to create a sensory gestalt of our immediate environment in working memory. The multi-modal convergence of sight, sound, smell, and touch relies on strong signal coupling between multiple sensory circuits, and the stability of this coupling relies on precise signal output timing from all circuits. If specific circuits become overly excited or overly inhibited, a divergence in circuit synchrony can create circuit instability that propagates throughout the entire network as a frame-translation error.

A good example of a simple frame-translation error can be found when analyzing the structure of phosphenes, the closed-eye geometric patterns seen when the optic nerve is excited. These swirling mandalas of the mind have been reproduced for thousands of years in spiritual artwork, but we now know that such patterns may be the direct result of instability in signal coupling between the spatially oriented neural structures in the retina and the visual cortex (see illustration to the left). If this instability is caused by excitation and lag in the feedback circuit connecting the LGN with the visual cortex, one would expect to see phantom frame data drifting across the visual field whenever the eyes were closed, creating the perception of spinning, luminescent mandalas.

Another example of a simple frame-translation error is a perceptible strobing of visible light, or frame-flicker, caused by divergent excitation between the optic nerve, the LGN, and the visual cortex. A more extreme version of this effect is total visual frame feedback, or flanging, where smooth perception is sliced into discrete frames of data which pile up on each other like visual echoes, often with a slight rotational effect. Flanging is the direct result of lag in recurrent signal convergence along the entire visual processing pathway.

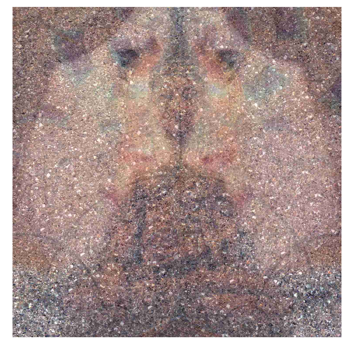
PERCEPTUAL DISTORTIONS CAUSED BY RUNAWAY RECURRENT EXCITATION

TRAILS AND AFTERIMAGES

One of the most common effects of psychedelics is visual trails. Afterimages of moving objects remain stuck in visual memory, creating smooth visual echoes which fade over a period of a few seconds. Recurrent excitation along the visual processing pathway traps sensory input from moving objects in the visual cortex the same way a camera’s “time lapse” shutter captures moving lights on optical film over time.

PERSPECTIVE DISTORTION

People under the influence of psychedelics often sense extreme distortion in perceptions of self and environment. A room may appear to “close in” as if being observed through a fish-eye lens. Conversely, parts of the body may seem to balloon to extreme proportions. These distortions in perspective are due to recurrent signal gain in the spatial and somatic cortexes, both expanding and contracting perceptions of space.

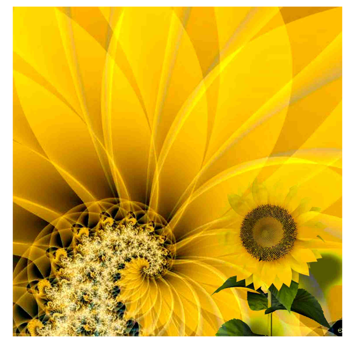


STOCHASTIC SMOOTHING

The human brain has a natural ability to find patterns in otherwise random noise, and this ability relies on recurrent analysis of visual stimulus. Psychedelics amplify this ability by increasing excitation in the object recognition cortex of the medial temporal lobe. In an excited state, the brain can discern and “paint” elaborate patterns on any field of noisy data, such as TV static, concrete (above), and other randomly distributed textures.

OPTIC FRAME FLANGING

As excitation is slowly introduced into the recurrent network, more and more signal is fed back upon itself with ever-increasing divergence in signal lag. The perceptual result is similar to feedback created when a video-camera is pointed at its own output. Discrete slices of perception begin to pile up on each other with a delay of a few milliseconds for each pass, creating an overlapping frame spiral that reaches toward infinity.



FRACTALLY RECURSIVE FLANGE

As the psychedelic trip hits its peak, the amount of signal noise generated by internal recurrent excitation begins to overshadow external sensory stimulus. At this point, the trip becomes “most psychedelic” as any stray thought or stimulus emerges holographically into consciousness as a self-referential fractal of infinite meaning. A simple sunflower recedes into an epic symbol of truth that can be grokked over and over, ad infinitum.

EXPANDED CONSCIOUSNESS AND RECURRENT IMPULSE FLOW CONTROL

OPTIMAL RATES OF RECURSION

In shamanic practice, the role of the Shaman is to help the patient navigate the various levels of the psychedelic journey. Presumably, the Shaman does this by mediating and fine-tuning the intensity and synchrony of recurrent feedback within the patient’s sensory processing pathways. This may be accomplished through precise dose targeting or other ritual means.

CRANIAL BLOOD FLOW

When trying to understand how psychedelics act as “non-specific amplifyers” of the psyche, it can be assumed that recurrent excitation caused by hallucinogens follows the path of bloodflow through the cranium. As an analytical circuit becomes excited and demands more blood, more drug is borne to that circuit via the bloodstream, further exciting the targeted circuit.

5-HT, DOPAMINE, AND GABA

Both 5-HT and Dopamine (DA) work together to mediate recurrent excitation. There are pre- and post-synaptic DA receptors that work in unison with 5-HT to focus and fine-tine recurrent excitation. And though slow lateral GABA inhibition is all but overpowered by runaway recurrent excitation, fast GABA pathways can still interrupt and redirect recurrent impulse flow.

RYTHMICALLY MEDIATED FLOW

The most effective drivers of synchrony in recurrent impulse flow are rythmically modulated sensory inputs, such as drumming, chanting, droning, and strobing lights. Sonically induced neural spikes tend to generate the greatest levels of synchrony between all sensory circuits, making music and dancing the perfect media for fine-tuning recurrent impulse synchrony, both individually and within groups.

BIOFEEDBACK MEDIATED FLOW

In the absense of external stimulus, the easiest way to modulate recurrent impulse flow is via targeted breathing and/or posture excercises found in yoga and other meditative practices. One of the reasons there is such a strong crossover between psychedelics and Buddhism is because both challenge you to master the most basic impulses of your own mind.

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